Eur J Appl Physiol (1987) 56:633–638

European Journal of
Applied
Physiology
and Occupational Physiology
© Springer-Verlag 1987

Physiological responses to fire fighting activities

Tiit T. Romet and John Frim

Defence and Civil Institute of Environmental Medicine, 1133 Sheppard Ave. W, P. O. Box 2000, Downsview, Ontario, Canada M3M 3B9

Summary. Eight professional fire fighters participated in six fire fighting scenarios at a training facility. Data on heart rate (HR), rectal temperature (T_{re}), and skin temperatures at the chest and thigh were collected using a portable data acquisition system. Average HR ranged from 122 to 151 beats·min^{-1} during the six scenarios. Detailed analyses indicated that HR and T_{re} increases are related to both the physical and environmental stresses of the various activities carried out. The most demanding activity, that of building search and victim rescue, resulted in an average HR of 153 beats·min^{-1} and T_{re} rise of 1.3°C, while the least demanding activity, that of the crew captain who directs the fire fighting, resulted in an average HR of only 122 beats·min^{-1} and a T_{re} rise of only 0.3°C. This study shows that fire fighting is strenuous work for those directly entering a building and performing related duties, but that the physical demands of other activities are considerably less. The results further suggest that heat strain injuries in fire fighters could perhaps be reduced by rotating duties frequently with other crew members performing less stressful work.

Key words: Fire fighter — Heat stress — Heart rate — Body temperatures — Portable data acquisition systems

Offprint requests to: T. T. Romet at the above address

Introduction

There is little doubt that fire fighting is a physically demanding occupation, and various studies have documented the environmental, physiological, and physical stresses of fire fighting duties. Abeles et al. (1973) have indicated that fire fighters often work in environmental temperatures ranging from 38 to 66°C, but that temperatures in excess of 200°C can be reached. Barnard and Duncan (1975) showed that physiological strain as determined by heart rate (HR) can be high, with HRs reaching near maximal values for extended periods of time. Duncan et al. (1979) showed later that the weight and insulating properties of the fire fighting protective clothing, especially in the heat, are major contributors to the observed high HRs. The energy cost of performing simulated fire fighting duties has been measured and is classified as heavy work (Lemon and Hermiston 1977). The result of this hard work under such conditions is a high rate of heat production leading to heat strain.

With most studies concentrating on the strenuous aspects of fire fighting, a notion has developed that all fire fighters work hard all the time, although it is unclear whether all activities lead to high HRs and metabolic heat build-up. This void exists mainly because of past difficulties in obtaining physiological data without interfering with the fire fighter's work. Today, however, it is possible to monitor physiological parameters continuously and unobstrusively with virtually no encumbrance to the subject by means of a portable solid state data recorder.

The present study, carried out to document the range of physiological responses that are associated with various activities, used such a system to obtain continuous recordings of HR, core and

88-00777/

skin temperatures on fire fighters engaged in routine exercises at a training facility, including exposure to heat and flames.

Methods

The subjects were eight healthy male fire fighters who volunteered for the study. Their mean age ± SD (years), height (cm) and weight (kg) were 34.3 ± 3.2, 178.5 ± 3.5 and 84.3 ± 4.0, respectively. The men were professional fire fighters and were accustomed to the work conditions encountered. Each subject wore standard fire fighting clothing which included cotton underwear, synthetic coveralls (Nomex), canvas overcoat and pants, rubber boots, gloves and helmet; for those entering the buildings, a cotton flash hood, mask and self-contained breathing apparatus (SCBA) were also worn.

Fire fighting was performed over a two day period at a training facility during which time the outside environmental temperature averaged 16°C. Six separate fire scenarios were presented, with two on the first day and four on the second. Each scenario required a group of five fire fighters with a pumper truck to respond to an alarm, approach the building, evaluate the situation, seach for and evacuate victims and extinguish the fires. All the activities were timed and recorded by observers, and the subjects were classified into one of four activity categories as follows:

a) Crew Captain — the individual who directed the fire fighting;

b) Lead Hand — the first individual(s) who entered the building, evacuated victims and/or were engaged in fire fighting;

c) Secondary Help — the individuals who entered the building at a later time and either helped extinguish fires or assisted in secondary searches of the building;

d) Exterior Fire Fighting — the individuals who operated water hoses outside the building or who drove and operated the pumper truck.

All temperatures were recorded from thermistors (Series 400, YSI Corp., Yellowsprings, Colorado, USA). Skin temperatures were measured on the chest and rear thigh, and rectal temperature (T_{re}) with a probe inserted 15 cm beyond the anus. Mean skin temperature ($\overline{T}_{sk}$) was estimated by averaging the two skin temperatures. The HR was taken from a standard ECG.

Data were collected continuously by a portable solid state data acquisition system (Vitalog PMS-8, Vitalog Corp., Palo Alto, California, USA). The recorder was programmed through its accompanying computer (Apple IIe) to record the three temperatures and average HR every 10 s for the duration of the day's activity. At the end of each day, the data were transferred back to the computer for permanent storage and later analysis. The individual subject data for HR and temperature were then further averaged over those subjects performing the same activities. Group means were analyzed by a one-way analysis of variance with post hoc multiple-comparisons performed according to Bancroft (1968).

Results

Data were collected for 23 man-runs during the six fire fighting scenarios. Subjects with incomplete data were not included in the analysis. Figure 1 shows as an example the HR and temperature responses of one subject who worked as the crew captain during the morning scenario and as the lead hand in the afternoon scenario.

Table 1 summarizes the average HR and temperature changes recorded for each group of subjects performing each scenario. Table 2 shows the comparisons in HR and body temperatures between the different fire fighting activities. Significantly higher ($p < 0.05$) HRs, rates of rise and total rise in Tre, and final $\overline{T}_{sk}$ for the lead hand activity were found when compared with any other activity. There were no significant differences between HRs or temperatures for the secondary help as compared to the exterior fire fighters. The crew captain showed the smallest changes of all the groups.

Figure 2, showing the relative temperature changes, further illustrates the progressive decrease in physiological strain experienced by the fire fighters performing different activities. Figure 3, indicating the percent time spent in three HR zones reflecting heavy, moderate and light work, shows the same pattern of decreasing stress.

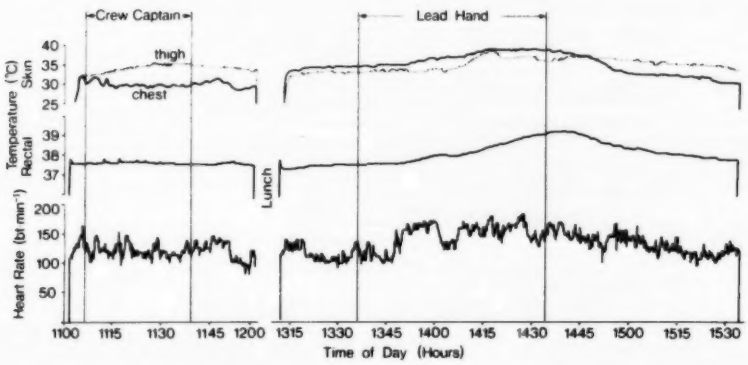

Fig. 1. Heart rate, core and two skin temperatures of one subject during Day 1 of the study. Two fire fighting scenarios are shown

Table 1. Average temperatures and heart rates during six fire fighting scenarios

	Day 1		Day 2				Mean
	Run 1	Run 2	Run 1	Run 2	Run 3	Run 4	
Duration (min)	32	48	25	20	27	20	
No. of Subjects	3	4	5	4	4	3	
Rectal (°C)							
Start	37.7	37.7	37.5	37.8	37.6	37.8	37.7
End	38.3	38.8	38.1	38.1	38.0	38.2	38.2
Δ	0.6	1.1	0.6	0.3	0.4	0.4	0.5
Chest (°C)							
Start	32.5	33.0	31.1	31.9	31.5	33.4	32.1
End	32.5	37.3	33.6	33.5	33.9	33.7	34.1
Δ	0.0	4.3	2.5	1.7	2.4	0.3	2.0
Thigh (°C)							
Start	34.0	33.8	32.7	33.5	33.2	33.5	33.4
End	36.9	38.0	36.6	35.4	35.8	35.7	36.5
Δ	2.9	4.2	3.9	1.9	2.6	2.2	3.1
HR (bt-min^{-1})							
Av. ± SD	143 ± 16	151 ± 17	127 ± 16	123 ± 20	123 ± 14	122 ± 18	131 ± 17
Range	92–193	79–183	77–162	77–162	88–178	88–182	

The data are averages over all crew members performing a variety of activities. Overall means for the six scenarios are also presented

Table 2. Comparison of heart rate and body temperatures between different fire fighting activities

Group	Lead hand	Secondary help	Exterior fire fighting	Crew captain
No. of Subjects	5	7	7	4
Duration* (min)	24.2	19.8	23.3	28.7
Rectal temperature				
Initial (°C)	37.7	37.7	37.6	37.6
S.D.	0.2	0.2	0.2	0.2
Rate of rise (°C-min^{-1})	0.032	0.022	0.016	0.009
S.D.	0.008	0.009	0.006	0.003
Total rise (°C)	1.3	0.7	0.4	0.3
S.D.	0.5	0.3	0.2	0.3
Initial T_{sk} (°C)	34.5	33.0	33.1	32.4
S.D.	0.6	0.4	0.4	0.5
Final T_{sk} (°C)	37.4	35.3	34.9	33.9
S.D.	0.4	0.5	0.6	0.5
Heart rate				
Average (bt-min^{-1})	153	130	123	112
S.D.	12	16	16	8
Resting (bt-min^{-1})	106	93	100	95
S.D.	10	15	12	6

* The average time the subjects performed the activity. Note, the lead hand and secondary help may have entered the building more than once during a scenario. (SD = Standard Deviation)

Discussion

The present study complements the work of Barnard and Duncan (1975) which described only the most physically demanding situations encountered by the fire fighter. Our results confirm their observations that HRs will rise to near maximum in the most stressful situations, but we further show that the changes are less severe in less demanding tasks. One might argue that the element

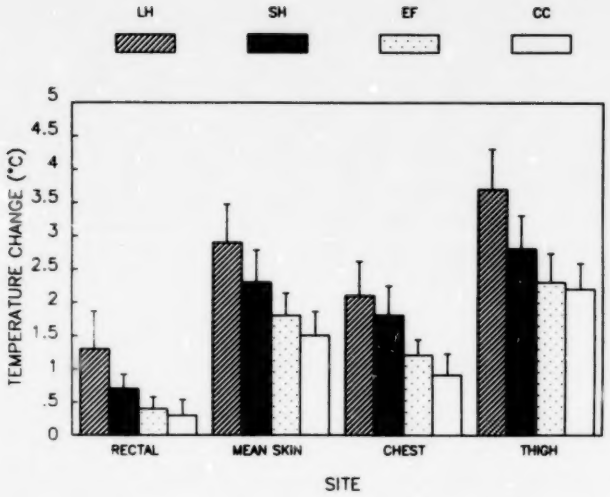

Fig. 2. Comparisons of the relative changes in body temperatures by subjects in each of the activity classifications. (*LH* = Lead Hand, *SH* = Secondary Help, *EF* = Exterior Fire Fighting, *CC* = Crew Captain)

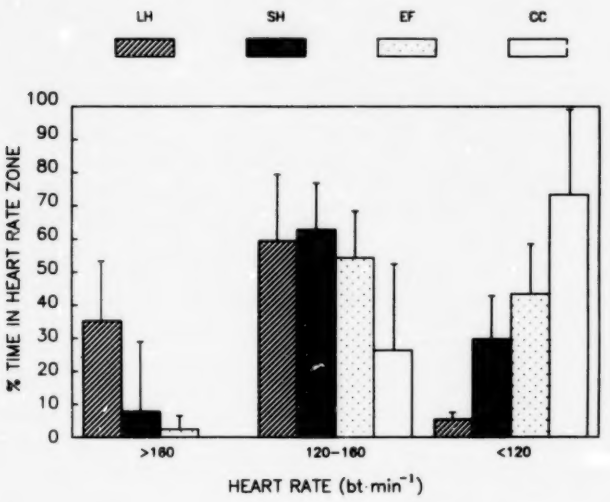

Fig. 3. Percent time spent in each of three heart zones by subjects in each activity classification. (*LH* = Lead Hand, *SH* = Secondary Help, *EF* = Exterior Fire Fighting, *CC* = Crew Captain)

of anxiety present in the Barnard and Duncan (1975) study was absent in our study, resulting in the lower HRs for certain tasks. However, since our fire fighters were being graded on their performances in an advanced fire fighting course, the element of anxiety may still have been high, albeit somewhat less and of a different quality than in a true emergency response situation. As well, we observed a small 10 to 15 beat·min^{-1} increase in HR at the beginning of the scenario as noted by Barnard and Duncan (1975). Further, under quite realistic fire fighting conditions, we have also confirmed the predictions from the simulation studies of Lemon and Hermiston (1977) that victim rescue and evacuation would be the most demanding activity.

We are unaware of any studies which have continuously measured rectal or skin temperatures during fire fighting and related them to HR or to specific fire fighting activities. This relationship could be quite complex since core temperature, skin temperature and HR all respond to work intensity as well as to environmental stress. While HR may not be an accurate measure of energy expenditure under all conditions, it can be used to judge work intensity provided other influences such as environment or subject fitness level are similar (Astrand and Rodahl 1977). On the other hand, Maxfield and Brouha (1963) showed that HR can also be a good indication of the severity of heat stress imposed upon working subjects. Kanon (1972) has demonstrated that HR

can increase 10 beats·min^{-1} per 10°C increase in ambient temperatures above 24°C. Similarly, while a rise in T_{re} in response to environmental heat in the absence of work may be intuitive, a rise in T_{re} directly related to the rise in HR during work is also well documented (Astrand and Rodahl 1977).

In this study, the changes we observed in both T_{re} and HR were not only reflections of the physical work being performed but also of the environmental conditions under which fire fighters work. Both T_{re} and HR can serve as criteria for the evaluation and prediction of heat strain (Kanon 1972). This is best exemplified by comparing the secondary help group activity with the others.

The secondary help, who like the lead hands entered the buildings and were exposed to the high environmental temperatures, showed smaller rises in T_{re} and HR than the lead hands. Since environmental conditions for both groups were so similar, the differences observed are probably the result of the higher energy expenditure by the lead hands. In other words, both T_{re} and HR responded to work intensity for the lead hands, over and above the responses expected to heat exposure alone. The average rate of rise for T_{re} would also confirm this conclusion, especially since exposure times to the inside of the building were not different. It should be noted that the higher initial $\overline{T}_{sk}$ for the lead hands is an indication that these fire fighters were completely dressed and prepared to immediately enter the building; this is also reflected in the higher resting HRs.

In comparing the secondary help group to the exterior fire fighters, they had slightly greater rises in T_{re} and higher average HRs. While the work intensity of the two groups may have been similar (Lemon and Hermiston 1977), the rise in T_{re} and possibly the increased HR for the secondary help were probably a thermal response to the heat stress of being inside a burning building.

The overall picture that emerges, therefore, is that during fire fighting both T_{re} and HR increase slightly in response to exterior work; body core temperature is then further increased by the addition of environmental heat stress to the same work intensity; and finally, both T_{re} and HR respond to an additional work load during heat exposure.

Although the data acquisition system has the capability of recording only two skin temperature sites, the average rises of 2.0 and 3.1°C to final temperatures of 34.1 and 36.5°C at the chest and thigh, respectively, are indicative of an increased thermal strain. A $\overline{T}_{sk}$ of greater than 35°C would indicate that heat build-up in the body is becoming the limiting factor in performing work (Christensen 1953). Although there are no well documented formulae using only two sites to calculate $\overline{T}_{sk}$, we believe that by averaging our two temperature sites, the chest which reflects the trunk, and the thigh which reflects the periphery, a reasonable estimate can be obtained. The groups that entered the building and were exposed to the higher environmental temperatures had two-point average $\overline{T}_{sk}$ greater than 35°C, indicating potential work decrement. Fanger (1970) states that a skin temperature of below 33°C would be necessary to maintain thermal comfort during increased physical activity, a condition never achieved by any group of fire fighters observed in this study.

Two practical concerns arising from this study warrant comment. First, a single 20 to 25 min exposure to the combined physical and thermal stresses of interior structural fire fighting as observed in this study would not appear to physiologically endanger a healthy individual. On major fires, however, a fire fighter may return to interior fire fighting duties several times, taking only sufficient time outside the building to change his SCBA air bottle. Given the slow rate of decline in core temperature it is extremely doubtful that the body would cool appreciably during such a short rest period, and this fire fighter would face an increased risk of succumbing to heat stress with each subsequent entry into the building. Since the SCBA typically provides breathing air sufficient for 15 to 30 min of hard work, a recovery period after depletion of an air bottle, achieved possibly by rotating duties with other crew members performing less demanding work, would help reduce such risks. Second, the high physical demands of certain fire fighting activities would indicate that the more physically fit individuals would be best suited for tasks involving building entry and victim rescue and evacuation. The same conclusion was obtained in a detailed study by Davis et al. (1982) who investigated the relationship between simulated fire fighting tasks and physical performance measures.

In summary, this study has shown that the physiological responses to fire fighting vary considerably with both the physical and environmental stresses to which the fire fighters are exposed. For the most demanding tasks, such as building search and victim rescue, HRs exceeding 150 beats·min^{-1} and rapid increases in T_{re} of over 1.3°C can be expected. For the physically least demanding activity, that of crew captain, HRs will seldom rise above 120 beats·min^{-1} with only

small rises in T_{re} or $\overline{T}_{sk}$. Frequent rotation of duties between stressful and less demanding tasks, possibly timed by SCBA air bottle depletion, may help reduce the risk of heat stress in fire fighters.

Acknowledgements. The authors would like to thank the subjects, the staff of the Canadian Forces Fire Academy at CFB Borden, and Capt. J. Wright of the Canadian Forces Fire Marshall's office for their co-operation. We also extend our appreciation to Mr. Robert Limmer and Miss Luxine Cheung for their technical assistance. This is DCIEM Report No. 87-P-22

References

Abeles FJ, Del Vecchio RJ, Himel VH (1973) A fire fighter's integrated life protection system. Phase I: Design and performance requirements. Grumman Aerospace Corp, New York

Astrand PO, Rodahl K (1977) Textbook of work physiology. McGraw-Hill, New York

Bancroft TA (1968) Topics in intermediate statistical method. Iowa State University Press, Ames, Iowa

Barnard RJ, Duncan HW (1975) Heart rate and ECG responses of fire fighters. J Occup Med 17:247–250

Christensen EH (1953) Physiological valuation of work in Nykroppa Iron Works. In: Lloyd WF, Welford AT (eds) Fatigue. H. K. Lewis, London

Davis PO, Dotson CO, Santa Maria DL (1982) Relationship between simulated fire fighting tasks and physical performance measures. Med Sci Sports Exerc 14:65–71

Duncan HW, Gardner GW, Barnard RJ (1979) Physiolgical responses of men working in fire fighting equipment in the heat. Ergonomics 22:521–527

Fanger PO (1970) Thermal comfort. McGraw-Hill, New York

Kanon E (1972) Ergonomics of heat and cold. Texas Rep Biol Med 33:145–182

Lemon PWR, Hermiston RT (1977) The human energy cost of fire fighting. J Occup Med 19:558–562

Maxfield ME, Brouha L (1963) Validity of heart rate as an indicator of cardiac strain. J Appl Physiol 18:1099–1104

Accepted April 29, 1987